Single-Phase Active Rectifier for On-Board EV Battery Chargers

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Abstract: Active rectifiers are used in on-board EV battery chargers as front-end converters to interface the power grid aiming to preserve the power quality. The paper provides an extensive overview of single-phase on-board integrated battery chargers for electric vehicles (EVs). Although commercial EVs are still to be equipped with integrated chargers, a multitude of topologies have been proposed for integration. This paper presents a novel single-phase active rectifier for applications of on-board EV battery chargers. The proposed active rectifier, with reduced number of semiconductors, is constituted by four MOSFETs and four diodes, and can produce five distinct voltage levels, allowing reducing the passive filters used to interface with the electrical power grid. An almost sinusoidal grid current with unitary power factor is achieved in the grid side for all the operating power range, contributing to preserve the power quality. The principle of operation, the current control strategy and the modulation technique are presented in detail. Simulation results in different conditions of operation are presented to highlight the feasibility and advantages of the proposed active rectifier.

Keywords: V Battery Charger; Five-Level Active Rectifier; Power Quality

I. INTRODUCTION

Recent fossil fuel shortage and global warming related problems have caused a substantial shift from internal combustion engine vehicles towards EVs. However, high battery price and slow charging process are still aggravating the change. At present, in nearly all commercial EVs, chargers are placed on-board as separate units. This to a large extent limits the charging power, since a charger rated for high powers would be too heavy to place on-board the vehicle. Moreover, it would also have a negative impact on the vehicle's weight, as well as on the required space under the bonnet. One possible solution to this problem is reutilization of existing power-electronics components. Namely, power electronic components that are used for the propulsion and those required for battery charging purposes are never used simultaneously. Since these elements are similar to each other, it is possible to allow some of them to perform multiple functions. If the same drivetrain is utilized for propulsion as well as for the charging process, the charging power is no longer limited by its size, cost and weight, since the drivetrain is already required for the propulsion.

Types of EV Chargers

EV chargers are classified into two types based on their energy transfer methods. Both the methods have different power electronics interfaces and their own advantages and limitations related to efficiency, usage, and the infrastructure.

- **Conductive Chargers:** These chargers have a hard-wired connection between the power source and the power converter that is used for charging the EV's. They usually consist of two stages, an active rectifier for power factor correction and a boost converter.
- **Inductive Chargers:** These chargers do not need a physical hard-wired connection with the power source to transfer the energy to the EV's battery system. They utilize primary (transmitter) and secondary (receiver) coils for power transfer using the magnetic induction principle.

Generally, a resonant converter transfers the power through the large air gap which is then rectified to charge the battery. Conductive chargers are more efficient compared to inductive chargers. However, the scope of applications is limited for conductive chargers. They only support "stationary charging", which requires the vehicle to be at a standstill condition for charging. On the other hand, inductive charger may support "en-route" charging in addition to stationary charging, which allows the vehicle to charge while it is in motion [5]. The scope of this paper covers only conductive chargers.

The problems with EV chargers are generally associated with multiple stages of power conversion; circulating currents in topologies with high-frequency transformers; losses in the switches; reverse recovery losses in the diodes; or the losses in the snubber circuits associated with the topologies. The reduction in the conduction losses is limited by the availability of the devices with low on-state voltage drop (or low RDSON in MOSFETS)

II. LITERATURE SURVEY

Composed on-board single-organize battery chargers for EVs are kept an eye on in this paper. Their working principles in the midst of the charging technique are clarified. The examination starts with courses of action that organize only the converter into the charging system, letting the machine alone for apparatus mode in the midst of the charging methodology. It is trailed by topologies giving both converter and SR machine the twofold helpfulness. The last inspected assembling contains topologies combining a converter and IM or PM machine into the charging method. Finally, topologies from all of the three social affairs are quantitatively pondered reliant on the usage of additional parts and the need of hardware reconfiguration between the working modes. [2]

An exploratory examination of single-organize dynamic rectifiers for electric vehicle (EV) battery chargers is shown and discussed. Dynamic rectifiers are used in on-board EV battery chargers as front-end converters to interface the power network proposing to secure the power quality. In this paper, four topologies of dynamic rectifiers are considered: standard power-factor-amendment; symmetrical bridgeless; and full-associate full-controlled. Such examination is set up with respect to the requirements for the gear structure, the multifaceted idea of the mechanized control system, and the power quality issues, essentially the network current total consonant mutilation and the power factor. A reconfigurable laboratorial model of an on-board EV battery charger related with the power arranges was used to gain the test outcomes. [3]

Network control quality essentials for on-board EV chargers are described through the IEC models on consonant current radiations. Regardless, with the wide association of EVs, these measures are at risk to future improvement covering a greater repeat band and stricter symphonies cut off focuses. Thusly, PFC battery chargers need to on a very basic level redesign the idea of the current drawn from the system. In this paper we included a data channel faltering in light of the PFC method with a single stage CSAR and proposed a working damping with resonation repeat following course of action that achieves the required consistence with the standards. For on-board chargers prepared for satisfying three-organize speedy charging and furthermore single-arrange moderate charging, deals in meeting the data channel's arrangement rules are unpreventable. [4]

Battery chargers for electric vehicles (EVs) are named on-board or off-board chargers [5]. Off board chargers are not obliged by size or weight but instead familiarize additional cost with the structure through the game plan of a high number of charging stations. With the ultimate objective to address the issues of EV customers to the extent charging openness, on-board chargers that achieve cooling/dc change are held. Also, on-board chargers are assigned stay lone or joined systems. By re-using parts of the balance control plan for charging, the last lessens the cost of the charger. Disadvantages of fused systems join electromagnetic closeness issues and complex control designs.

Solid state switch-mode change converters have accomplished a created dimension for upgrading power quality to the extent control factor amendment (PFC), lessened total symphonies mutilation at information AC mains and completely coordinated DC yield in buck, bolster, buck-help and amazed modes with unidirectional and bidirectional power stream. This paper deals with an exhaustive review of improved power quality converters (IPQCs) setups, control approaches, structure features, assurance of parts, other related considerations, and their sensibility and decision for specific applications. It is engaged to give a wide range on the status of IPQC development to authorities, organizers and application engineers tackling traded mode AC-DC converters. An arranged summary of more than 450 research preparations on the state of forte of IPQC is also given for a lively reference. [6]

An on-board charger is responsible for charging the battery pack in a module creamer electric vehicle (PHEV). In this paper, a 3.3kW two stage battery charger design is presented for a PHEV application. The objective of the structure is to achieve high efficiency, or, at the end of as far as possible the charger measure, charging time and the whole and cost of intensity drawn from the utility. The action of the charger control converter game plan is given despite a point by point plan system. The mechanical packaging structure and key preliminary outcomes are given to affirm the sensibility of the proposed charger control building. [7]

This paper displays a novel three-arrange buck-type solidarity control factor rectifier legitimate for high power Electric Vehicle battery charging mains interfaces. The characteristics of the converter, named the Swiss Rectifier, including the standard of action, direction strategy, sensible control structure, and dimensioning conditions are depicted in detail. In addition, the proposed rectifier is appeared differently in relation to a standard 6-switch buck-type cooling dc control change. According to the results, the Swiss Rectifier is the topology of choice for a buck-type PFC. Finally, the attainability of the Swiss Rectifier thought for buck-type rectifier applications is displayed by techniques for a gear demonstrates. [8]

This paper presents test eventual outcomes of electric vehicle (EV) action as a detached uninterruptible power supply (UPS). Other than the traditional network to-vehicle and vehicle-to-system modes, this paper demonstrates an improved vehicle-to-home action mode. This new movement mode includes the area of a power outage in the power organize and the distinction in the EV battery charger control to function as a separated UPS. Exactly when the power lattice voltage is restored, the voltage conveyed by the on-board EV battery charger is step by step synchronized with the power arrange voltage before a whole change to the commonplace mode. This paper presents eventual outcomes of two figurings to recognize a power outage: the root mean square (rms) check technique subject to half-cycle of the power grid voltage, and the rms estimation reliant on a Kalman channel. The test outcomes were gotten in persisting and transient state considering two cases with the EV associated at home: while charging the batteries and without charging the batteries. This paper depicts the EV battery charger, the power outage area strategies, and the voltage and current control techniques. [9]

This paper demonstrates a model insightful stream control associated with another topology of single-switch three-level (SSTL) dynamic rectifier, or, at the end of the day an application for single-organize battery charger for electric vehicles (EVs). In the midst of each testing period, this present control plot picks the state of the SSTL dynamic rectifier to confine the screw up between the system current and its reference. Using this framework, it is possible to procure sinusoidal system current with low total symphonies bowing and unitary power factor, or, at the end of the day the standard essentials for EVs chargers. The paper shows in detail the working rule of the SSTL dynamic rectifier, the propelled control figuring, and the EV battery charger combining the SSTL dynamic rectifier used for the preliminary check. The obtained results certify the correct utilization of the model judicious current control associated with the proposed SSTL dynamic rectifier. [10]

In light of the extending power usage of server ranches, capable dc control dispersal systems have transformed into a basic subject in research and industry throughout the latest years and concurring standards have been gotten. In addition the power eaten up by media transmission equipment and server ranches is a money related factor for the apparatus overseer, which surmises that all parts of the flow structure should be planned to restrict the presence cycle cost, i.e. the aggregate of first cost and the cost of the influence change incidents. This paper demonstrates how semiconductor advancement, chip area, appealing section volumes and trading repeat can be picked subject to life cycle cost, using logical and numerical upgrades. A three-arrange buck-type PFC rectifier with facilitated dynamic channel for 380V dc course systems is used for example structure, which shows that an apex capability of 99% is truth be told and fiscally pragmatic with best in class SiC MOSFETs and nanocrystalline or ferrite focuses. Estimations gone up against a 8 kW, 4 kWdm-3 gear show display the authenticity and plausibility of the arrangement. [11]

An epic flying-capacitor-secured five-level inverter reliant on augmentation estimated traded capacitor topology is proposed in this paper. The inverter incorporates the traded capacitor circuit with dc-dc boosting change limit and the stunned inverter circuit with flying-capacitor-propped execution. With the novel composite structure, the amount of fragments is cleaved down stood out from the topology of the standard fell stunned inverter. Meanwhile, some bit of switches can be worked under line voltage repeat, realizing trading hardship decline. Along these lines, the ability of system adequacy and power thickness is released due to introduce traded capacitor circuit. Even more basically, the streamlined transporter based stage way beat width balance strategy is used as a control method. Under this control system, the capacitor voltage self-levelling can be recognized and nature of yield waveforms can be improved on a very basic level. After re-enactment, the model is attempted to favour the rightness and practicability of the examination. [12]

Amazed inverters have made another deluge of energy for industry and research. While the set up topologies have wound up being a down to earth choice in a broad assortment of high-control medium-voltage applications, there has been a working excitement for the improvement of fresher topologies. Decline in overall part consider appeared differently in relation to the set up topologies has been a fundamental objective in the starting late exhibited topologies. In this paper, a part of the starting late proposed amazed inverter topologies with diminished power switch check are surveyed and inspected. The paper will fill in as an associate and an invigorate with these topologies, both in regards to the emotional and quantitative parameters. Also, it considers the challenges which rise when an undertaking is made to lessen the contraption count. In perspective of a quick and dirty relationship of these topologies as displayed in this paper, appropriate amazed plan can be met up at for a given application. [13]

This paper shows an upgraded five-level bidirectional converter (iFBC) controlled by restricted control set model farsighted control (FCS-MPC). This control framework involves in using the discrete time nature of the iFBC to portray its state in each testing between time. Using FCS-MPC the trading repeat isn't enduring; in any case, it is sensible to seek after the present reference with low total symphonies contorting (THD). The iFBC display that was remarkably made for getting test results is depicted in detail along the paper, and furthermore its standard of action, control speculation, and current control procedure. The iFBC was probably endorsed related with the power organize as the second advanced demand L f C f inactive channel filling in as a working rectifier and as a system tie inverter. For both movement modes, the preliminary outcomes confirm the incredible execution (to the extent efficiency, low current THD, and controlled yield voltage) of the iFBC controlled by FCS-MPC. [14]

This paper deals with a power factor review (PFC)- based Cuk converter-supported brushless dc motor (BLDC) drive as a fiscally sagacious response for low-control applications. The speed of the BLDC motor is controlled by moving the dc-transport voltage of a voltage source inverter (VSI) which uses a low repeat trading of VSI (electronic pay of the BLDC motor) for low trading mishaps. A diode associate rectifier sought after by a Cuk converter working in an unpredictable conduction mode (DCM) is used for control of dc-interface voltage with solidarity control factor at cooling mains. Execution of the PFC Cuk converter is evaluated under four assorted working conditions of uncontrollable and steady conduction modes (CCM) and an examination is made to pick a most suitable strategy for errand. The execution of the proposed structure is reproduced in a MATLAB/Simulink condition and a hardware model of the proposed drive is made to support its execution over a broad assortment of speed with solidarity control factor at cooling mains. [15]

In this paper, the standard of disengagement is used to gather the particular amazed voltage and current source converter topologies. The paper is essentially based on high-control applications and especially on high-voltage dc systems. The decided converter cells are treated as building squares and are adding to the deliberate nature of the system. By joining the particular building squares, i.e., the converter cells, an arrangement of voltage and current source estimated stunned converter topologies are induced and totally discussed. Plus, by applying the deliberate quality standard at the system level, various types of high-control converters are exhibited. The deliberate nature of the stunned converters is inspected all around, and the troubles and the open entryways for high-control applications are depicted. [16]

The specific stunned converter (MMC) has been a subject of extending centrality for medium/high-control imperativeness change structures. Throughout ongoing years, basic research has been done to address the specific challenges related with the errand and control of the MMC. In this paper, a general chart of the stray pieces of assignment of the MMC nearby its control challenges are discussed, and a review of front line control strategies and examples is shown. The uses of the MMC and their challenges are highlighted. [17]

In this paper another single-arrange five-level buck-help dynamic rectifier is exhibited called capacitor tied switches (CTS). The proposed rectifier has two free DC yields that can be related with two extraordinary weights. Unmistakable trading states and the typical strategy for the proposed topology are analyzed to structure the related controller goes for coordinating the two yield DC voltages, creating five-level voltage at the commitment of the rectifier in conclusion draw solidarity control factor and sinusoidal current from AC system. From AC network see, the rectifier works in lift mode at any rate the made DC voltage can be part into two separate yields which may be not actually the AC peak voltage or altogether more prompts work in both buck and lift action mode. Full propagation results are showed up and analysed to favour the suitable movement and incredible amazing execution of the proposed five-level buck-encourage rectifier. [18]

This paper displays a lone stage single-switch bridgeless power factor corrector (PFC) help Vienna rectifier as an introduced electric vehicle (EV) battery charger. The showed topology makes 3-level voltage waveform at the data which discards consonant substance on a very basic level while using little channels. The reduced number of parts used in this topology makes it connecting with for EV endeavours to develop this PFC rectifier as an insignificant battery charger. Exhibiting of the single-arrange Vienna rectifier is performed and a fell PI controller is proposed to deal with the DC transport voltage at 400V to charge EV batteries and also drawing low symphonies cross section current and ensuring solidarity control factor action of the converter. Proliferations are done to favour the incredible amazing execution of the single-switch rectifier and grasped controller in delivering coordinated and low swell DC voltage from AC lattice to supply EV batteries. [19]

This paper indicates new three-level unidirectional single-organize PFC rectifier topologies fitting for applications concentrating on high profitability or conceivably high power thickness. The properties of a picked novel rectifier topology including its models of errand, change procedure, input control scheme, and a power circuit arrangement related examination are shown. Finally, a 220-V/3-kW investigate office show is created and used with the ultimate objective to affirm the qualities of the new converter, which join incredibly low trading hardships and single cooling side lift inductor, that consider a 98.6% zenith capability with a trading repeat of 140 kHz. [20]

III. PROPOSED SYSTEM

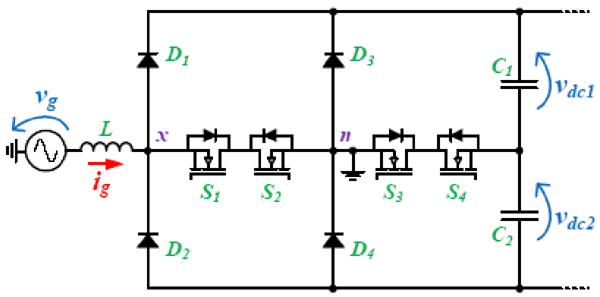

Fig.1. five level active rectifiers for EV battery chargers

Operation of active rectifier is described as follows:

Switch S1 and S4 are OFF

Input voltage varies between 0 and +V_dc/2 V

When input voltage varies between 0 and +V_dc/2 V and switch S2 is ON and S3 is OFF the output voltage is 0V (a) whereas if S2 is OFF and S3 is ON then output voltage is V_dc/2 V. (b)

Input voltage varies between +V_dc/2 V and+V_dc

When input voltage varies between +V_dc/2 V and+V_dcand switch S2 is ON and S3 is OFF the output voltage is +V_dc/2 V (c) whereas if S2 **is** OFF and S3 is OFF then output voltage is 〖+V〗_dc V. (d)

Switch S2 and S3 are OFF

Input voltage varies between 0 and -V_dc/2 V

When input voltage varies between 0 and -V_dc/2 V and switch S1 is ON and S4 is OFF the output voltage is 0V (e) whereas if S1 is OFF and S4 is ON then output voltage is -V_dc/2 V. (f)

Input voltage varies between -V_dc/2 V and-V_dc

When input voltage varies between -V_dc/2 V and-V_dcand switch S1 is OFF and S4 is ON the output voltage is -V_dc/2 V (g) whereas if S1 is OFF and S4 is OFF then output voltage is 〖-V〗_dc V. (h)

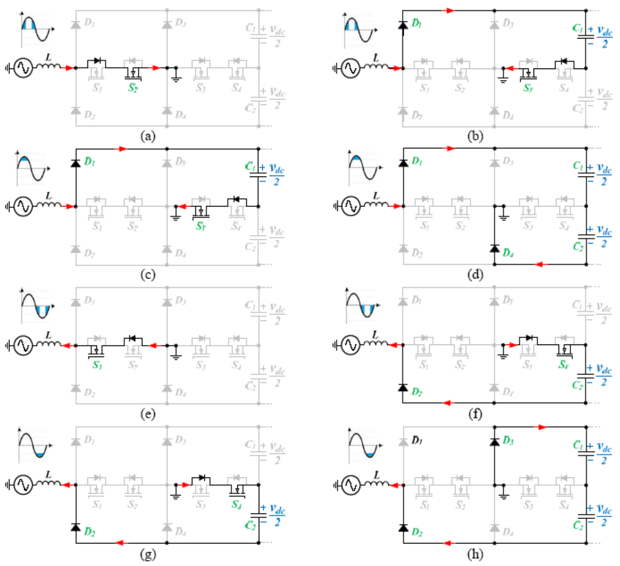

Fig.2. operation of proposed rectifier

Stages of operation of the proposed single phase five level active rectifier are given below:

a) Var = 0 V – When the produced voltage varies between 0V to +Vdc/2;

b) Var = +Vdc/2 V – When the produced voltage varies between 0V to +Vdc/2;

c) Var = +Vdc/2 V– When the produced voltage varies between +Vdc/2 to +Vdc;

d) Var = +Vdc V– When the produced voltage varies between +Vdc/2 to = +Vdc;

e) Var = 0 V – When the produced voltage varies between 0V to -Vdc/2;

f) Var = -Vdc/2 V– When the produced voltage varies between 0V to -Vdc/2;

g) Var = -Vdc/2 V– When the produced voltage varies between -Vdc/2 to -Vdc;

h) Var = -Vdc V– When the produced voltage varies between -Vdc/2 to -Vdc.

IV. PRINCIPAL OF OPERATION

The proposed active rectifier allows to produce five distant voltage levels (+Vdc, +Vdc/2, -Vdc/2 and -Vdc), i.e., the voltage between the points x and n identified in figure 3.1. The analysis is performed for two quadrants, i.e., positive voltage with positive current, and negative voltage with negative current.

During the positive half cycle the MOSFET’s S1 and S4 are always OFF. when the voltage produced by the active rectifier varies between 0 and +vdc/2 are switched the MOSFET’s S2 and S3. when the MOSFET S¬¬2 is ON and the MOSFET S3 is OFF the voltage produced is 0 (fig.2(a)) and when the MOSFET S2 is OFF and the MOSFET S3 is ON the voltage produced is +Vdc/2 (fig.2(b)). when the Voltage produced by active rectifier varies between +vdc/2 and +vdc, the MOSFET S2 is OFF the MOSFET S3 is switched. when the MOSFET S3 is ON the voltage the produced is +vdc/2 (fig.2(c)), and when The MOSFET S3 is OFF the voltage produced is +vdc(fig.2(d)).

On the other hand, during the negative half cycle the MOSFET S2 and S3 are always OFF. when the voltage produced by active rectifier varies between 0 and -vdc/2 are switched the MOSFET S1 and S4. When the MOSFET S1 is ON and the MOSFET S4 is OFF the voltage produced is 0 (fig.2(e)) and when the MOSFET S1 is OFF and the MOSFET S4 is ON the voltage produced is -vdc/2 (fig.2(f)), and when the voltage produced by the active rectifier varies between -vdc/2 and -vdc, the MOSFET S1 is OFF and the MOSFET S4 is ON the voltage produced is -vdc/2 (fig.2(g)), and when the MOSFET S4 is OFF the voltage produced is -Vdc (fig.2(h)).

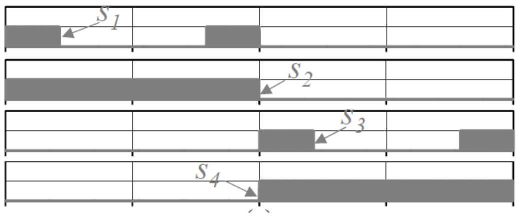

Fig.3. MOSFET's pulse-patterns (S1, S2, S3and S4)

V. SIMULATION AND RESULTS

The proposed active rectifier was validated through the computer simulation using the MATLAB v2015a software.

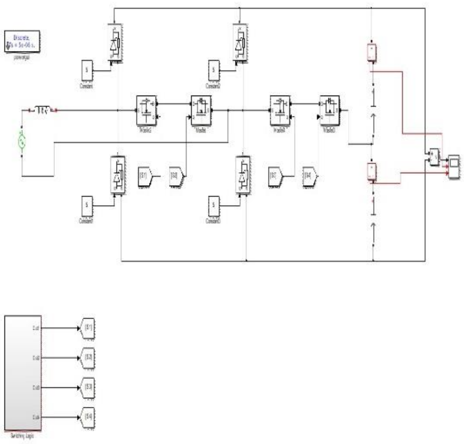

Fig.4. Actual Simulation model in MATLAB

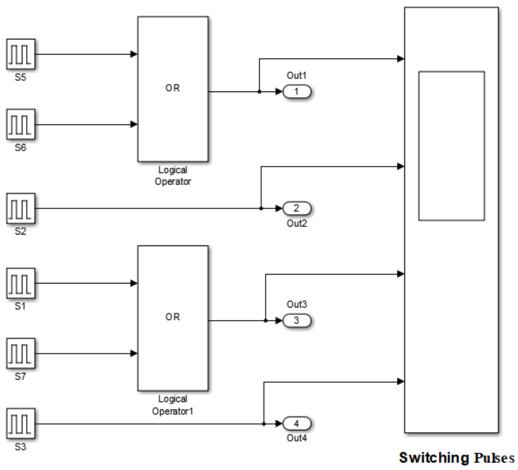

Fig.5. Switching logic

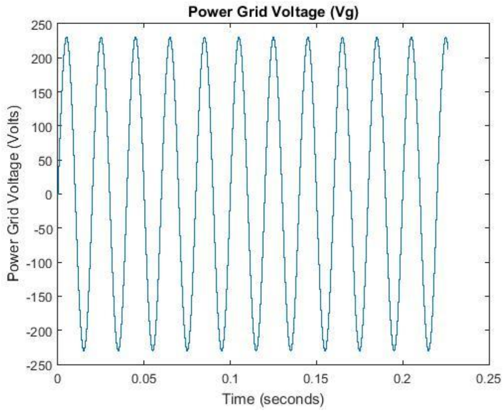

Fig.6. Power Grid Voltage (Vg)

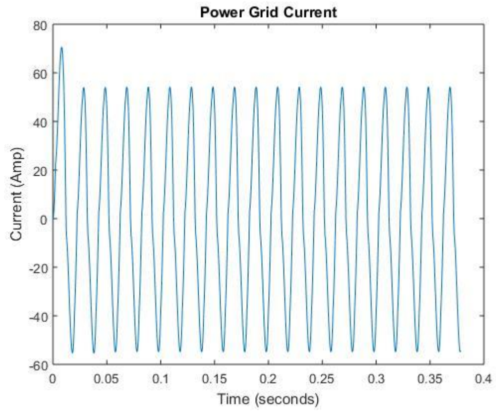

Fig.7. Power Grid Current (Ig)

As we got Pure sinusoidal wave for Power grid voltage and Power grid current with this rectifier.

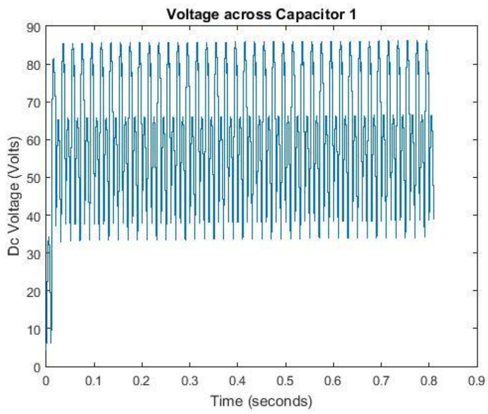

Fig.8. Output voltage across capacitor 1

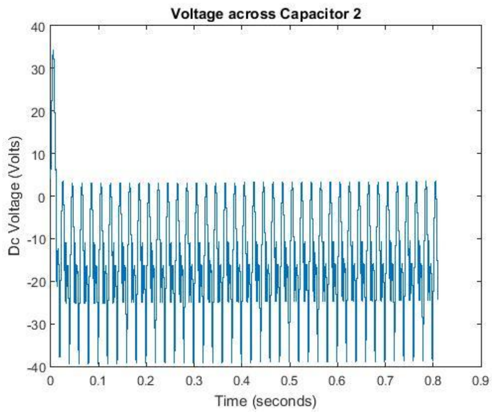

Fig.9. Output voltage across capacitor 2

We got Positive output DC Voltage at capacitor 1 as shown in fig 8 and Negative Output DC Voltage across capactor 2. The rectified voltage at output side is shown in fig.10.

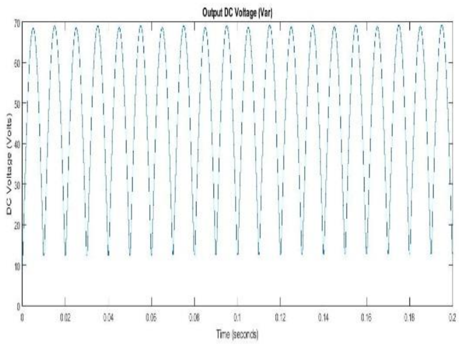

Fig.10. Rectified Dc Voltage (Var)

VI. CONCLUSION

Integrated on-board single-phase battery chargers for EVs are reviewed in this paper. Their operating principles during the charging process are elaborated. The analysis commences with configurations that integrate only the converter into the charging process, leaving the machine in idle mode during the charging process. It is followed by topologies giving both converter and SR machine the double functionality. The final analyzed group consists of topologies incorporating a converter and IM or PM machine into the charging process. Finally, topologies from all three groups are quantitatively compared based on the use of additional elements and the requirement of hardware reconfiguration between the operating modes.

The designed On-Board Electric Vehicle charger is of two stage type whereas a single stage prototype can be designed which will reduce the losses associated with the components and maximize efficiency. Moreover, the Boost PFC converter is designed with an analogue controller the digital mode of the controller can be designed which can be implemented using microcontrollers.

A Bi-directional isolated DC-DC converter can be designed for both G2V and V2G modes and can operate as LDC. To reduce the switching losses a ZVS or ZCS topology of the designed DC-DC converter can be developed which will reduce the losses associated with the switches during turn ON or turn OFF.

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